DOI 10.1007/s11041-014-9778-x
Metal Science and Heat Treatment, Vol. 56, Nos. 7 – 8, November, 2014 (Russian Original Nos. 7 – 8, July – August, 2014)

UDC 621.785.52:669.15-194.2

EFFECT OF THE CONTENT OF RETAINED AUSTENITE AND GRAIN SIZE ON THE FATIGUE BENDING STRENGTH OF STEELS CARBURIZED IN A LOW-PRESSURE ATMOSPHERE

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Translated from *Metallovedenie i Termicheskaya Obrabotka Metallov*, No. 8, pp. 40 – 43, August, 2014.

The effect of the content of retained austenite and of the initial austenite grain size on high-cycle fatigue of two low-alloy steels 16MnCr5 and 17CrNi6-6 after carburizing in a low-pressure atmosphere (acetylene, ethylene and hydrogen) and subsequent high-pressure gas quenching is investigated.

Key words: low-alloy steels, retained austenite, vacuum carburizing, fatigue strength.

INTRODUCTION

Vacuum carburizing of materials hardens the surface layer and gives rise to compressive stresses, which should influence considerably the fatigue bending strength [1 – 10]. In this case, application of a cyclic bending load shifts the center of formation of microcracks into the depth of the material outside the hardened layer, and the compressive stresses hinder crack propagation [1 – 3].

The advantages of vacuum carburizing over conventional hardening methods manifest themselves obviously in the resistance to fatigue fracture. Elimination of internal oxidation prevents formation of surface indentations, which can become foci of fatigue. Another feature of vacuum carburizing, which affects the fatigue resistance, is the use of gas quenching instead of oil quenching after the carburizing. Quenching in a high-pressure gas provides a clear metallic surface of the part. The parts subjected to such treatment are ready for assembly immediately after the process, if the quenching deformations do not exceed the permissible tolerance range [4 – 10]. It should be noted that the surface of an oil-quenched part should virtually always be ground, which is known [11] to cause tensile stresses on the surface thus lowering the fatigue resistance. At the same time, a change in the hardening method may change the content of retained austenite in the surface layer of the steel. In its turn, this can affect the stresses influencing the fatigue strength.

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Carburizing in a low-pressure atmosphere (LPC) or vacuum carburizing makes it possible to raise the temperature of the process and thus to intensify the latter. However, this can promote grain growth, which may affect the fatigue strength negatively.

The aim of the present work was to study the effect of the grain size and of the content of retained austenite on the fatigue bending strength of specimens of steels 16MnCr5 and 17CrNi6-6 subjected to vacuum carburizing followed by high-pressure gas quenching.

METHODS OF STUDY

The effect of the retained austenite and of the grain size of the primary austenite on the fatigue bending strength was estimated using the results of measurements performed for steels 16MnCr5 and 17CrNi6-6, the chemical composition of which is presented in Table 1.

Using the recommendations of the ASTM E 606-04 Standard [12], finite-element simulation of deformations and stresses, and experimental results we determined the optimum shape and sizes of a sample from the standpoint of provision of desirable deformations (stresses) and investigation of the low-cycle fatigue resistance by the resonance method (Fig. 1) [1, 2].

The shaped samples were annealed in vacuum at 860°C for normalizing their structure and removing the internal stresses. The mean grain size after the heat treatment was 10 μm. Then the surface of the sample (with curvature radius R28) (Fig. 1) was ground with a grinding wheel covered with

TABLE 1. Chemical Compositions of Steels 16MnCr5 and 17CrNi6-6

Steel	Content of elements, wt.%						
	C	Mn	Si	Cu	Cr	Ni	S
16MnCr5	0.18	1.21	0.37	0.16	0.98	0.19	0.03
17CrNi6-6	0.17	0.50	0.28	–	1.48	1.56	0.02

cubic boron nitride (CBN) at the places where we expected the appearance of fatigue cracks in order to eliminate surface indentations capable to produce a negative effect on the results of the experiments.

After grinding, the samples were subjected to carburizing in an low-pressure atmosphere by the FineCarb® process at 920°C [13]. The process was conducted to obtain an effective thickness of the layer ECD = 0.6 mm (the criterion of carbon concentration was 0.4 wt.%) at a carbon content on the surface of 0.75 wt.%. To provide the specified profile of carbon concentration the duration of the stages of the process were chosen on the basis of the mathematical model of the SimVaC Plus® program. Carburizing in the low-pressure atmosphere was performed in a universal VPT-4022/24IQN furnace with an option of high-pressure gas quenching (HPGQ). Right after the carburizing, the samples were quenched from 860°C in a nitrogen atmosphere at a pressure $p = 1.2$ MPa and then subjected to low tempering at 180°C. In addition, steel 16MnCr5 was carburized at 1000°C so as to form a diffusion layer similar to that obtained at 920°C.

The fatigue bending strength was determined by a modified high-frequency resonance method that involved monitoring of the resonance frequency of the vibration system with one degree of freedom due to formation of a focus of fatigue. The fatigue strength was measured in terms of the number of bending cycles applied to the sample until a change in the resonance frequency of the whole system.

Each change in the frequency of free vibrations signaled the appearance of fatigue defects in the sample. After the thermochemical treatment the specimens of steels 17CrNi6-6 and 16MnCr5 were studied for high-cycle fatigue strength by the resonance method using induction hardening coils 5010/LS-80 produced by the TIRA (Vibration Test System, Germany). The bending of the sample was determined using a laser extensometer equipped with an LTC 120-40 measuring head (MTI Instrument Inc.). The experiment was performed on 16 samples for each treatment variant. The load for each sample was chosen by a step method based on the specific elongation strength *Rm*; the value of 0.7*Rm* was chosen as the initial load. The load amplitude was controlled by varying the parameters of the forcing signal in the hardening coil at the specified resonance frequency, which allowed us to determine the stress value. The stress arising in the system was determined from the shift of the free end of the sample with respect to the fixed end. To determine the whole range of the fatigue strength the load was changed stepwise [1 – 3].

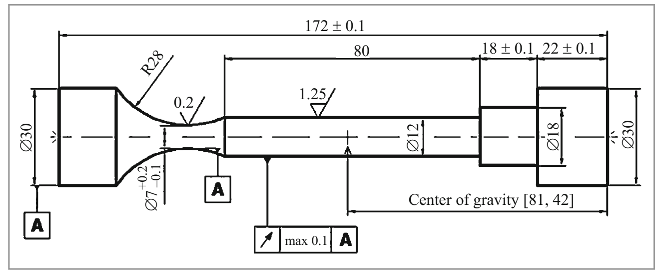

Fig. 1. A sample for studying fatigue bending strength by the method of [1, 2].

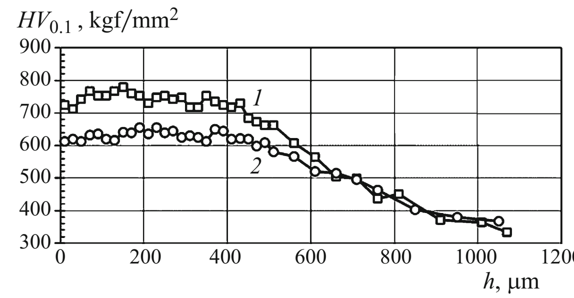

Fig. 2. Distribution of microhardness over the thickness of hardened layer in steels 16MnCr5 (*1*) and 17CrNi6-6 (*2*) after vacuum carburizing at 920°C, gas quenching, and low tempering [2] (*h* is the distance from the surface).

Pendulum bending of the samples was implemented at the resonance frequency for each sample at a constant amplitude of the tilt of the free end. The moment when a fatigue crack appeared was determined from the change in the resonance frequency.

RESULTS AND DISCUSSION

Despite the same treatment parameters and the same gradient of carbon concentration in the surface layer the hardness of the layer in steel 17CrNi6-6 was lower than in steel 16MnCr5. The surface hardness of steel 17CrNi6-6 was 600 $HV_{0.1}$, that of the core was 330 $HV_{0.1}$, the effective thickness of the layer in terms of the hardness criterion of 550 $HV_{0.1}$ was about 0.60 mm (Fig. 2). The hardness of the surface of steel 16MnCr5 was about 720 $HV_{0.1}$; that of the core was 320 $HV_{0.1}$ at the same effective thickness of the layer. The lower hardness of the diffusion layer of steel 17CrNi6-6 as compared to steel 16MnCr5 is a result of the higher content of retained austenite (Fig. 3). According to the data of the x-ray study it amounts to 34 ± 3.6% at a distance of 150 μm from the surface. This is more than twice higher than in steel 16MnCr5 carburized and quenched under the same conditions (Fig. 4). No precipitate or cluster of carbide has been detected in the structure of the surface layer in steel 17CrNi6-6 and in steel 16MnCr5 (Fig. 3).

The diameter of the former austenite grains in steel 17CrNi6-6 after carburizing was 15.1 μm. We obtained vir-

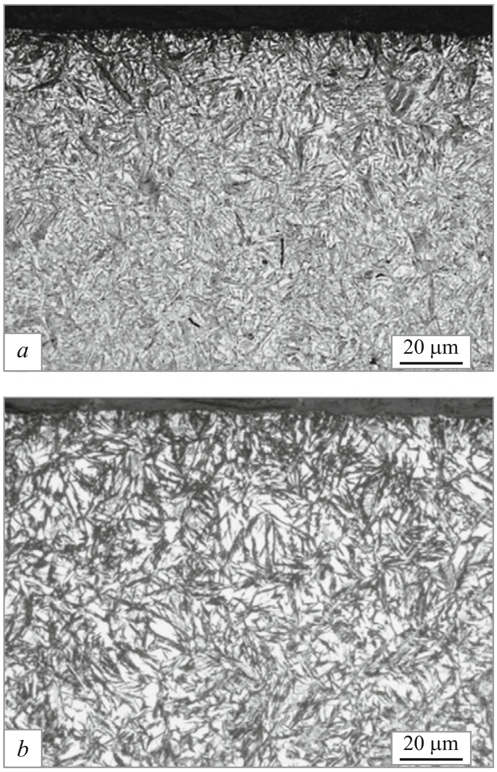

Fig. 3. Microstructure of steels 16MnCr5 (*a*) and 17CrNi6-6 (*b*) after vacuum carburizing at 920°C. Etching with Nital [3].

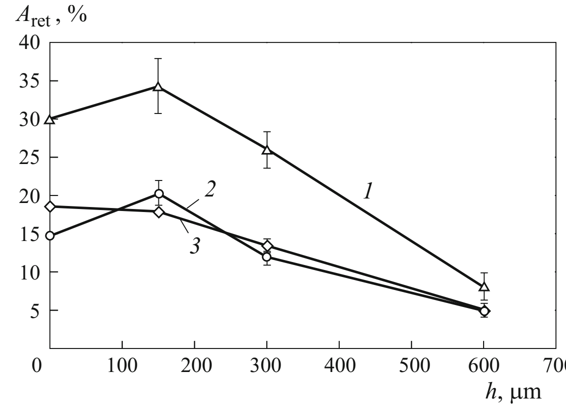

Fig. 4. Content of retained austenite in the surface layer of steels 16MnCr5 (*2*, *3*) and 17CrNu6-6 (*1*) after vacuum carburizing at 920°C (*1*, *2*) and 1000°C (*3*) [3] (*h* is the distance from the surface).

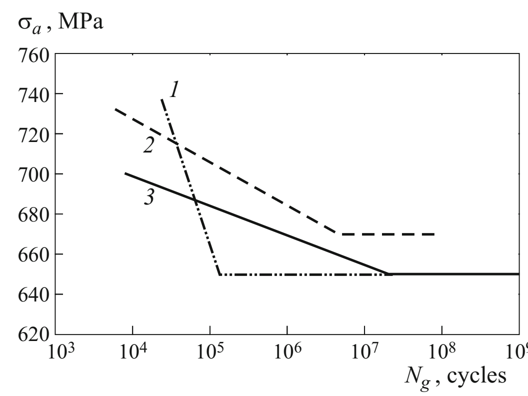

Fig. 5. Diagrams of limited and unlimited fatigue of steels 17CrNi6-6 (*1*) and 16MnCr5 (*2*, *3*) after vacuum carburizing at 920°C (*1*, *2*) and 1000°C (*3*) [3] [1, 2, 14].

tually the same grain diameter in steel 16MnCr5 after carburizing in a low-pressure atmosphere at 1000°C (Table 2). The mean size of the former austenite grains in steel 16MnCr5 carburized at 920°C was lower (Table 2).

The bending fatigue strength of steel 17CrNi6-6 after low-pressure carburizing was lower than that of steel 16MnCr5 (Fig. 5). It should be noted that both steels had been carburized earlier under similar conditions. This concerns both limited and unlimited fatigue strength. Steel 17CrNi6-6 attained the same fatigue limit (Z_{g0} = 650 MPa) as steel 16MnCr5 after carburizing in a low-pressure atmosphere at a temperature of 1000°C, when the grain size of the former austenite in it was close to that observed in steel 17CrNi6-6.

With allowance for the fact that the yield strength of steel 17CrNi6-6 is higher than that of steel 16MnCr5 we could expect that the ultimate bending strength of this steel should also be higher. However, the fatigue resistance of steel 17CrNi6-6 after vacuum carburizing at 920°C turned out to be lower from the standpoint of ultimate fatigue strength. The limiting number of cycles $N_g = 10^5$. In such a case the plasticizing of the material intensifies, and nucleation of a fatigue crack is determined not only by the grain size but also by the content of retained austenite.

TABLE 2. Mean Grain Size of Primary Austenite (d_m) in Steels 16MnCr5 and 17CrNi6-6 after Vacuum Carburizing and High-Pressure Gas Quenching

Steel	T_{car}, °C	d_m, μm
16MnCr5	920	11.2
16MnCr5	1000	15.1
17CrNi6-6	920	15.5

CONCLUSIONS

1. Growth in the size of former austenite grains in steel 16MnCr5 due to increase in the carburizing temperature causes lowering of both limited and unlimited fatigue bending strength.

2. Growth in the content of retained austenite in the surface layer of steel 17CrNi6-6 as compared to that of steel 16MnCr5 after carburizing at the same temperature (920°C) lowers the fatigue bending strength and reduces the limiting number of loading cycles as compared to the specified level.

3. Despite the higher yield strength of steel 17CrNi6-6, its bending fatigue strength is lower than that of steel 16MnCr5, which is explainable by the larger size of the former austenite grains and the higher content of retained austenite in steel 17CrNi6-6.

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